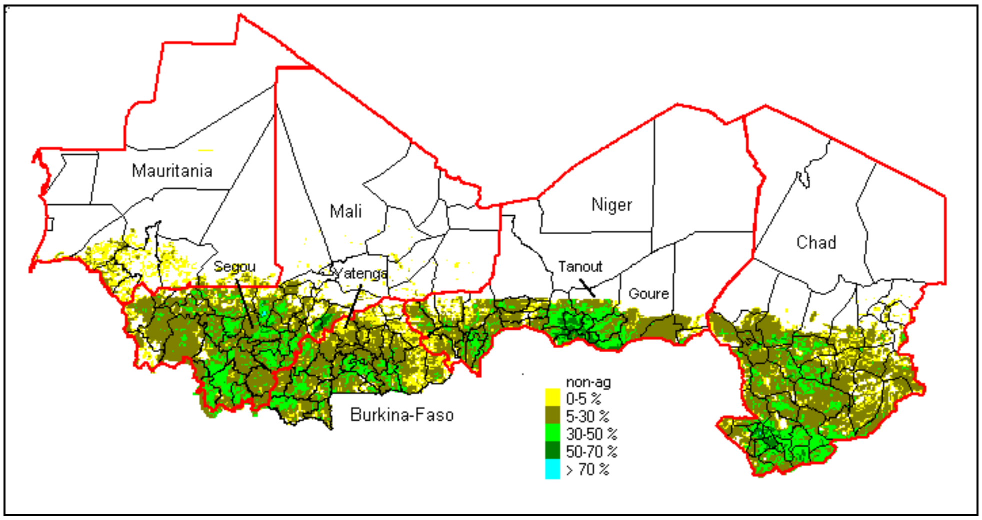
Status Report on Crop Use Intensity (CUI) Applications in the FEWS Project



FEWS Working Paper

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1. Introduction

Agricultural production is one of the key ingredients for monitoring food security - whether during the course of a given agricultural season, or, at the time of the final harvest figures. Adequate knowledge of where important crops are grown is crucial for monitoring the vast area covered by the FEWS project in sub-Saharan Africa. The more precisely we can locate the important cropping areas, the better we can identify the effects of drought and climatic anomalies on the potential agricultural production of a given area. Since the majority of people in sub-Saharan Africa depend on some type of agricultural production for their livelihood, improving our knowledge of where crops are grown should also improve our ability to target populations who may be susceptible to food security problems related to agricultural production.

Detailed land-use maps, depicting the location of major croplands, are not readily available for many countries in sub-Saharan Africa. This was especially evident in the early days (of FEWS) when field representatives were compiling existing reference maps and data. Accurate, detailed land-use maps were conspicuously absent from the baseline information.

Cropland Use Intensity (CUI) maps were proposed in 1990 by the USGS as a means to address the need for information and maps identifying the location of important crop-lands. CUI maps are derived from high resolution (Landsat) satellite imagery and represent different levels of agricultural activity, or percent cropping, on a country-wide basis. The concept of CUI mapping was developed in the 1970's to assist scientists who were conducting the Large Area Crop Inventory Experiment (LACIE) to study agricultural production using Landsat imagery. A system was needed to classify large land areas into various levels of cropland and non-cropland to help monitor agricultural production potential. The results of the LACIE experiment were also used by agricultural services to estimate crop production potential in foreign countries, where accessibility and alternative sources of data were at a minimum (see Dalsted and Westin report for details on LACIE and CUI development).

The primary objective of using CUI in the FEWS project is to distinguish agricultural lands from non-agricultural lands to improve our ability to monitor the most important agricultural areas. Specifically, CUI has been used for two principal monitoring applications within the FEWS project:

1) To stratify NDVI imagery, that helps with image interpretation and improves the extraction of temporal and spatial statistics from the images, and,
2) To redistribute agricultural statistics, reported by national governments, from general administrative units to sub-administrative units and important agricultural areas.

The use of CUI in the FEWS project has been an evolving process, beginning in 1990 with Niger and continuing into southern and eastern Africa in recent years. The CUI maps and digital files have been used by FFRs and others for various applications, but an overall evaluation of the utility of CUI for FEWS monitoring has never been conducted. Comments have been received from the field on the accuracy of the maps and on the potential applications, but there is not an operational CUI product, per se, in use by the FEWS project.

The purpose of this review is to document what has been done in the area of CUI development and usage in the field and in FEWS/W, and to evaluate the utility of CUI in the context of the FEWS project.

This review examined three main components, or aspects, of CUI:

1. Verification of the Landsat interpretation and original CUI maps.
2. The use of CUI to stratify NDVI images for extraction of statistics.
3. The use of CUI to redistribute agricultural statistics.

The first area involves the original CUI classification from the Landsat imagery. To understand the potential applications of the CUI product, we first wanted to look at what was being represented on the maps, relative to what is discernible on the Landsat images. This step also incorporates comments from the FFRs who have been involved in informally verifying the CUI classes on the ground.

A major effort went into the second area - evaluating the use of CUI for extracting NDVI statistics. Several study sites were selected to represent areas with “known” agricultural status, i.e. high, medium, and low, in terms of agricultural production and agro-ecological zones. Three sites were selected in the Sahel and one in southern Africa. The results of NDVI statistical extraction, with and without CUI classes will be presented in detail.

The third area, redistributing agricultural statistics, was not studied in-depth at this time but will be briefly discussed in the context of several previous studies that used this technique.

Since the focus of this review is in the context of the FEWS project , some background will be presented to describe two basic monitoring applications used by “the typical FFR”. Following the background section will be a discussion of the CUI classes and the verification process, a description of the selected study sites, and a presentation of results and recommendations.

2. Background on FEWS monitoring techniques

2.1. Stratification of NDVI images.

An important component of the FEWS project's early warning and monitoring approach involves the use of satellite imagery to monitor vegetation development during the growing season. The primary type of satellite data used in this approach are the NDVI (Normalized Difference Vegetation Index) images derived from the NOAA-AVHRR satellite sensor. Since it is well established that NDVI is highly correlated with the amount of biomass on the ground, these images can be used to indicate current vegetation conditions as well as identify deviations from normal conditions during the growing season.

NDVI data are routinely used by most FFRs and FEWS/W staff for continent-wide analyses of vegetation conditions. Most of the time NDVI images are color-coded and visually analyzed as a map (see Figures 1 and 2). In map form, NDVI values are interpreted by color, showing shades of green where vegetation is well developed, and yellow or brown for areas where there is little or no vegetation.

Another analysis tool routinely used by FEWS is NDVI difference images (Figures 1 and 2). Difference images are derived by subtracting current NDVI images from the long-term average image, or from the previous 10-day period (dekad). NDVI difference values are usually coded green, where the vegetation development is above normal, and red, where the development is below normal. A basic interpretation of these images is fairly straightforward - if this difference is positive, this implies that there is more vegetation present than is usual, or, that the vegetation is developing slightly ahead of its normal pattern when compared to the previous decade, or, to the average. If this value is negative, you can deduce that there is less vegetation present, or, the vegetation is developing behind schedule. This simple - green is "good" and red is "bad" map - has become, more-or-less, a standard FEWS product.

However, the interpretation must always be made with some caution and adequate knowledge of the spatial distribution of cropping and pasture systems, as well as a feeling for the normal pattern or trends in annual vegetation development in the area. Most FFRs are familiar enough with their countries to know, in general, where the agricultural and pastoral zones are relative to desert regions, forests, national parks, and other non-agricultural lands. This allows FFRs and analysts to focus their monitoring of NDVI, at least visually, to the regions of their country where agriculture and pastoral activities are the most important.

Figure 1. Example of NDVI maps (W. Africa)

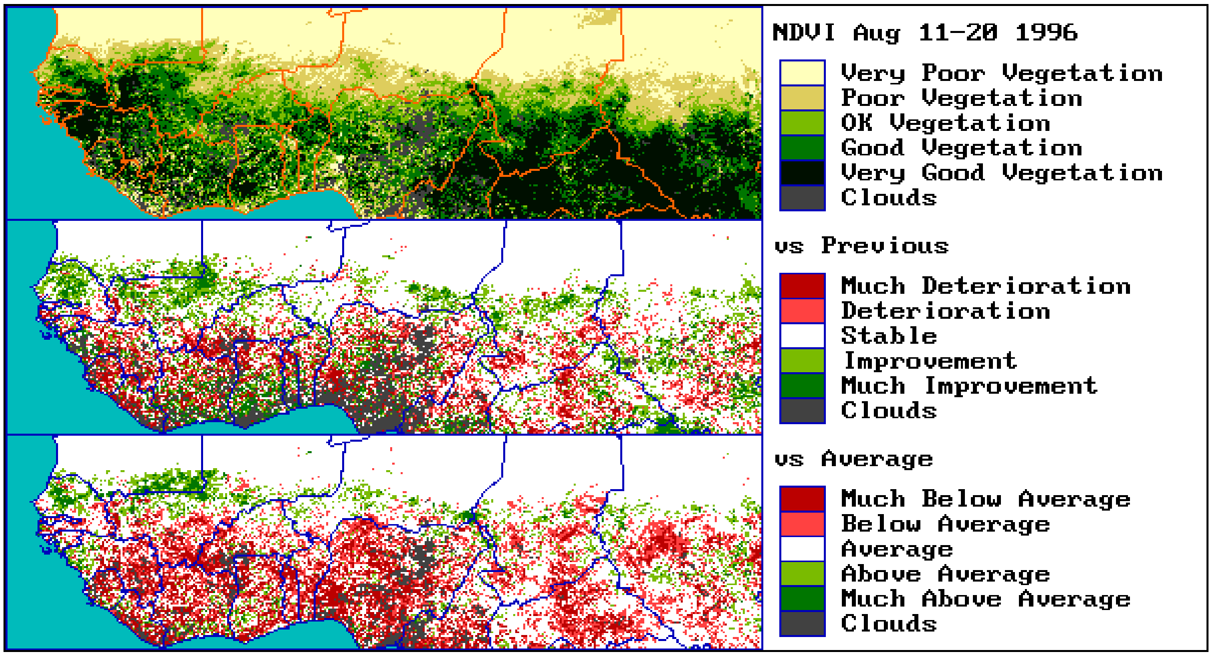
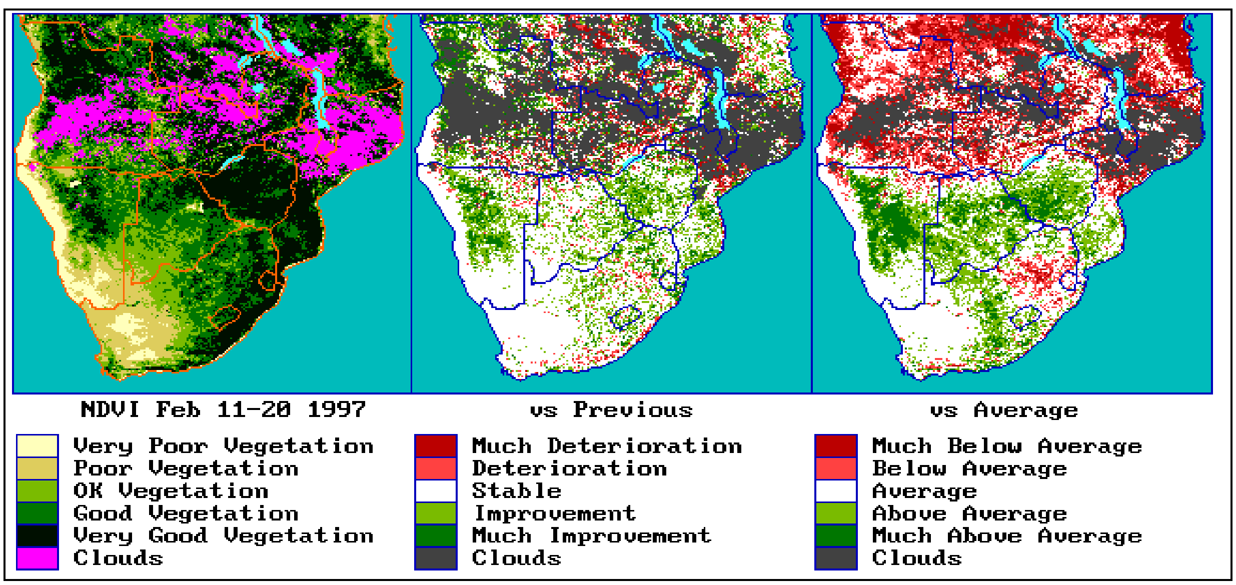


Figure 2. Example of NDVI maps (S. Africa)



These NDVI data can also be used in a more quantitative sense by analyzing the temporal and spatial variability of certain descriptive statistics derived from imagery. This level of analysis is not necessarily routine, but is used by some FFRs, at least on an annual basis, to derive indicators which can be used in the vulnerability assessment (VA) process. However, to use the NDVI data quantitatively requires the analyst to understand the nature of the NDVI values at a much more detailed level. Typically, this would involve extracting descriptive statistics (e.g. average NDVI, maximum NDVI, standard deviation of NDVI, etc.) summarized across an entire administrative unit (e.g. arrondissement, district, department, province, canton, etc.). Extracting these statistics or running these programs is not particularly complicated, but there are several steps involved and it can be somewhat cumbersome and time-consuming.

There have been several software programs developed under the FEWS project to make it easier for the FFRs to extract statistics from NDVI images and analyze temporal trends (e.g. SPACEMAN, VAST = Vegetation Analysis in Space and Time). The SPACEMAN software extracts and stores NDVI statistics and enables the analyst to produce graphic outputs that show the temporal trends in NDVI values (such as, the average NDVI compared to the current year's NDVI for a given administrative unit). The VAST program was also developed under FEWS-II to create images of various statistics (as opposed to the graphic outputs). Example outputs from the VAST program would be images showing the start of season, maximum NDVI of the season, and length of season.

The results from doing NDVI analysis using these tools, such as SPACEMAN and VAST, are dependent in part on the spatial resolution of the imagery. Spatial resolution can be thought of as the level of detail that each cell, or pixel, in the image represents on the ground. The NDVI data used in the FEWS project are referred to as Global Area Coverage (GAC) and has a spatial resolution of approximately 7 km. This resolution works well for monitoring large areas (countries and regions) and especially if the terrain is homogeneous (e.g. extensive pasture lands, or millet/sorghum zones). The interpretation of NDVI trends, especially at GAC resolution, is more difficult and questionable in complex terrain with intricate agro-ecological zones (e.g. Ethiopia and Rwanda).

The SPACEMAN routine is further hampered by size of the polygons used to extract the statistics from the images. These statistics are usually extracted by administrative units, typically, level 3 or 4. However, the administrative units are not always the most effective way to capture the desired information - such as seasonal trends in NDVI values or anomalies from an established norm (e.g. max, min, cumulative, etc.). This problem is especially true in those countries with large administrative units that stretch across very diverse terrain.

In spite of these limitations, the SPACEMAN and VAST software continue to be useful for extracting statistics to illustrate and analyze the temporal trends using the administrative boundaries as the sampling units. Indicators derived from NDVI statistics have been used by FFRs in several countries, especially for the annual VA (e.g. RVA, Niger, Malawi, Zambia).

Even with GAC resolution and complex terrain the quantitative use of NDVI could be improved by controlling the size and type of polygons that are used as the sampling unit. Instead of using administrative units that we know are too large for the analysis, a more appropriate way to extract statistics might be to use some type of agro-ecological strata, or, a simple agriculture vs. non-agriculture mask to isolate the areas of interest. Using an agriculture mask should reduce the effects of mixed terrain, especially in large areas that range from desert to crops.

This is the basic idea of the first proposed use of CUI - as a means to stratify the NDVI imagery to isolate the major agricultural zones prior to extracting NDVI statistics.

Technical Note: The SPACEMAN software has been revised to run in a Windows environment and is one of the new FEWS Data Managers developed in conjunction with USGS. The VAST capabilities are not yet available under Windows, and therefore requires a higher level of expertise on the part of the FFRs. Some FFRs are more comfortable with these steps than others, but this level of NDVI usage is by no means routine in the field. Assistance is often provided by FEWS/W to those field sites, on a country-by-country basis, that would like to have the NDVI summary images created for use in their VA analysis. Of course, any type of NDVI analysis assumes that the values are properly calibrated and geo-referenced so that the inter-annual comparisons can be made with some degree of confidence (which is NASA’s domain).

2.2. Redistribution of agricultural statistics.

Another important component of FEWS monitoring is the analysis of national agricultural statistics that are used to estimate agricultural production - during the course of the growing season, and after the final harvests. Agricultural statistics are a major input into the final food needs assessments and play an important role in targeting vulnerable populations and identifying cereal deficit zones. However, in many of the FEWS countries, these agricultural statistics are collected at a very general scale (e.g. level 3) and it is difficult to extrapolate the results to lower administrative units (e.g. level 4). For example, in Chad, most agricultural production data exists at the 2nd administrative unit (e.g. préfecture), whereas early warning alerts and food aid responses are required at a much smaller level (e.g. sous-préfecture or below).

Typically national agricultural statistics are reported at the 3rd administrative unit. However, many of the administrative units are not entirely agricultural zones, and we would like to redistribute the agricultural statistics proportionally to the areas of greatest importance to agricultural production. One method to accomplish this would be to simply disaggregate the level-3 statistics to the next administrative level (e.g. level-4) by making some assumptions about what percentage to attribute to each unit, for example, proportionally by relative area. However, it is not necessarily a valid assumption that the agricultural production at one level is proportional to the next administrative level. For example, in the arrondissement (level 3) of Tanout in Niger, the largest canton (level 4) has the least amount of agricultural land, and the smallest canton has the most agricultural land. This is a fairly common situation (at least in the Sahel) and we would like a more representative way to disaggregate the production statistics.

Another technique to disaggregate agricultural statistics is by using some type of agro-ecological or crop use stratification. Using this method, the level 2 statistics could be redistributed to the most productive areas, weighted according to the level of cropping or agricultural intensity. Theoretically, this would result in a more detailed, spatial representation of how the agricultural production is distributed throughout the administrative unit.

This is the basic idea of the second proposed use of CUI maps - as a means to redistribute the agricultural statistics into more meaningful agricultural production zones.

The application of CUI to disaggregate agricultural statistics was not studied in-depth in this review. Although it is desirable to obtain agricultural production data at a sub-national level, there are several important factors to consider before pursuing this approach using existing agricultural statistics. From a statistical sampling perspective, the national agricultural statistics are designed to provide reliable production estimates at a certain level and are not necessarily valid below that level. That is, the sample size needed for reliable national-level statistics would be smaller, due to the smaller variability inherent in the national-level statistics, than the sample size needed for reliable sub-national level statistics. As the size of the area decreases, the variability typically increases, and so would the necessary sample size. A sampling design for the 3rd administrative level, with sampling errors on the order of 15-20 percent may be acceptable **at that level** for national planning purposes.

However, additional errors would be introduced as the agricultural statistics are redistributed to new areas as given by the CUI (or any type of crop mask or stratification technique applied after the samples have already been collected). Given the uncertainty in the quality of the agricultural statistics, and, without a quantitative figure for the accuracy of the CUI maps, we would not have a great deal of confidence in the redistributed statistics. In some cases, if information is lacking and the redistributed data are "better than nothing", in may be acceptable to proceed with this type of analysis.

Another issue involves the creation of new administrative units from the redistribution process. Most of the FEWS reporting is done at some minimum, baseline level, usually the 3rd or 4th level administrative unit. For reporting purposes, the data we collect and analyze needs to be consistent with the reporting level that is optimum (or at least, feasible) for each country. The reporting units are also usually the same units that are used by the local government institutions. If new sub-units of analysis are created, there would not likely be any other information available for these same units, nor, a historical perspective at these new, derived units. For example, agricultural production data, food stocks, health information, and price data, are all collected relative to some administrative unit. Perhaps more detailed, sub-administrative-unit information is collected on field trips, using some form of Rapid Rural Appraisal (RRA) technique, however, this type of information is difficult to systematically combine with the other baseline data. FEWS is currently looking at ways to improve the use of this qualitative information, such as RRA data, census and demographic data, and information derived from field trips.

3. Description of original CUI classes and verification status.

Dalsted and Westin (1996) have described in detail the background of CUI and results of preliminary verification studies. The CUI maps are based on interpretation of Landsat imagery, generally at a scale of 1:200,000. Five classes have been established to approximate different levels of cropping, in percentage terms, as given in Table 1. Modifiers are added to the CUI class to represent general landform/landcover classes, such as water, alluvial lands, wetlands, sandy lands, rocky lands, and large urban areas. If they can be discerned, developed irrigation lands and recessional agriculture are also noted. Perennial crops are not represented in the CUI system at present.

Table 1.

CUI Class	Percent Cropping
CUI 1	70-100
CUI 2	50-70
CUI 3	30-50
CUI 4	5-30
CUI 5	0-5

The CUI classification system was verified in the initial stages of development as a means to estimate cropland in the north-central plains states of the U.S (North and South Dakota and Montana). Cropland area estimates derived from CUI were within 4 percent of the USDA estimates for the same region (Westin and Brandner, 1980). There have been no large-scale, quantitative verification studies done for the use of CUI in the sub-Saharan Africa context. However, several small-scale projects have attempted to verify the CUI analysis in the field using airborne videography as part of a natural resource management project and as a proxy for population density (Bruner et al., 1995, in Niger), and, to evaluate land-use change in eastern Africa (Crawford et al., 1996, in Mozambique). USGS (Klaver, 1995) also provides some preliminary results of using CUI and NDVI to monitor rainfed agricultural zones in Niger (discussed in results section).

FFRs are uniquely positioned to help in the CUI verification process, although lack of time to do so is the biggest factor. They have been involved in field testing the CUI maps, either as part of their routine field trips, or, as a separate exercise (e.g. Mali, Niger, Chad, Somalia). Guidelines for assessing the CUI maps were prepared by FEWS/W and USGS in the summer of 1996 and distributed to all the FFRs with CUI. These guidelines recommended a template that could be completed in the field to give the location information (e.g. country, village, date, odometer reading) as well as a simple description of the agricultural status (e.g. crops or non-crops, some relative percentage). Results from these field sheets could then be used (by USGS) to help verify and modify, if needed, the CUI maps and interpretation key. The CUI verification templates were not completed by FFRs as systematically as was initially anticipated by USGS, but there was some response from the FFRs as to the accuracy of the CUI maps.

Comments from the FFRs are summarized as follows (from field notes and memos):

- the locations of the higher and lower crop intensities seem reasonably close to reality on the ground,
- CUI appears to provide a meaningful stratification, even though it is not an absolute measure of crop use,
- for large political divisions, especially in the Sahel, CUI provides useful information for differentiating desert areas from rangelands and agricultural zones,
- for certain areas, CUI seems to under- or over- estimate crop intensity, perhaps since the imagery used to generate the CUI maps date from the mid-1980s and recent population and climatic changes have affected crop use patterns.

In general, comments are favorable and FFRs are optimistic for the potential applications of CUI. The principal investigator for the CUI mapping effort, K. Dalsted, also provided comments from field verification trips in Niger and Mali (see Dalsted memos and reports). Several of the FEWS/W staff also reviewed the original CUI overlays examples that were sent from USGS, along with the corresponding Landsat images. These examples were for the Sahelian region only. General comments from reviewing the CUI overlays at the FEWS/W office are:

- as the FFRs indicated, the general location of high intensity and low intensity croplands appear as one would expect (e.g. major rice areas of Mali, southern zones in the Sahel are generally more intensive agricultural than the northern zones, the “bread-basket” in Niger stands out as a major agricultural zone, etc.),
- some areas of recessional agriculture may be absent in southern Chad and parts of Mali (as was pointed out in the field notes given above),
- some questions regarding the large homogeneous areas (CUI4) in Niger and Chad,
- in southern Mali, there are large homogeneous blocks adjacent to areas with very fine detail (CUI3, the “lumpers” vs. the “splitters” problem in image interpretation, as well as most systems of classification, such as, botany, agronomy, etc.),
- in general, there is a question of consistency of the CUI classes between countries, e.g. is a CUI3 in southern Burkina-Faso the same as a CUI3 in central Niger or eastern Chad?

Even though there may be limitations to the CUI classification, for the next section, we assumed that the CUI groupings are reasonable and looked at how these data can be used in the context of the FEWS project, especially for improving the extraction of statistics from NDVI data.

4. Description of NDVI study sites

To evaluate the effects of CUI on NDVI statistical extraction, the author selected several study sites to represent different agricultural conditions. The sites were selected to illustrate various levels of agro-ecological conditions, concentrating mostly on the Sahel.

1) Tanout, Niger, to illustrate a large administrative unit that includes desert, rangeland, and agriculture, in the Sahelian zone (e.g. 400-600 mm of annual rainfall).
2) Yatenga, Burkina-Faso, to illustrate a moderate zone, between the Sahelian and Sudanian zones (600-1200 mm of annual rainfall).
3) Segou, Mali, to illustrate an intensive agricultural area, in the Sudanian zone
4) Mumbwa, Zambia, to illustrate a intermediate rainfall and agricultural production area in southern Africa (e.g. 500 - 700 mm of annual rainfall).

Three basic scenarios were used at each study site to extract NDVI statistics.

1) The average NDVI based on the entire administrative unit.
2) The average NDVI within the administrative unit with significant agriculture (CUI).
3) The average NDVI within the administrative unit with varying degrees of vegetation based on the long-term maximum NDVI image.

The first case is identified by the administrative unit name only, depending on the country (e.g. TANOUT, Niger; YATENGA, Burkina-Faso; SEGOU, Mali; MUMBWA, Zambia). The second case was to extract average NDVI statistics only from those areas identified as being intensive agricultural zones based on the CUI class within the administrative unit (e.g. CUI class 1, 2, and 3, see Table 1). For each study site a polygon was hand-drawn (in IDA) to represent the major agricultural areas from the CUI image supplied by USGS. These cases are labeled with the abbreviated administrative unit name followed by CUI (e.g. SEGCUI, TANCUI, etc.). Figure 3 shows the CUI image and the location of the three West Africa study sites.

The third case was to extract average NDVI statistics using a “vegetated vs. non-vegetated” mask derived from the historical NDVI database. To estimate areas that are vegetated or not, an image was created showing the maximum NDVI value attained for each pixel for the entire database. The assumption here is, if a pixel has never reached a value of 0.12 throughout the 12-year data series, it is probably not a major vegetation zone. A minimum threshold value of 0.12 is a fairly conservative estimate and most likely represents a rangeland or mixed agriculture area. This image was color coded to essentially show “vegetation or not”. These cases are labeled with the abbreviated administrative unit name followed by AVE (e.g. SEGAVE, TANAVE, etc.). Figure 4 shows the long term, maximum NDVI image and the location of the study site in Niger to illustrate the three levels of extracting statistics.

Figure 3. CUI Image and Study Sites for West Africa.

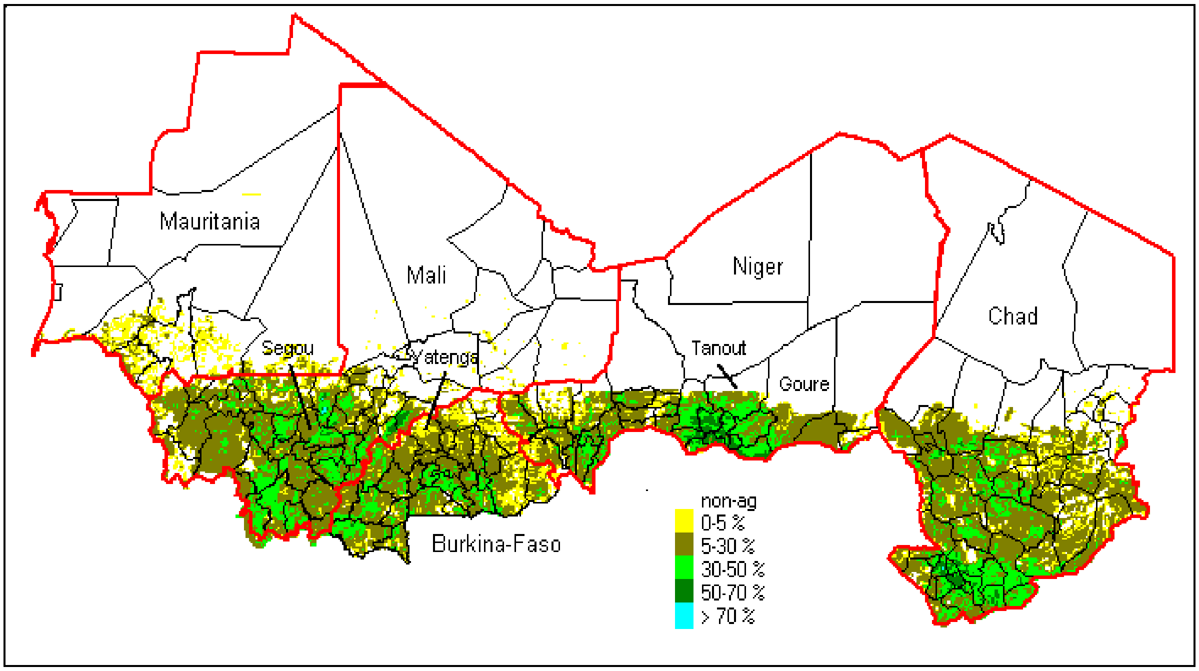
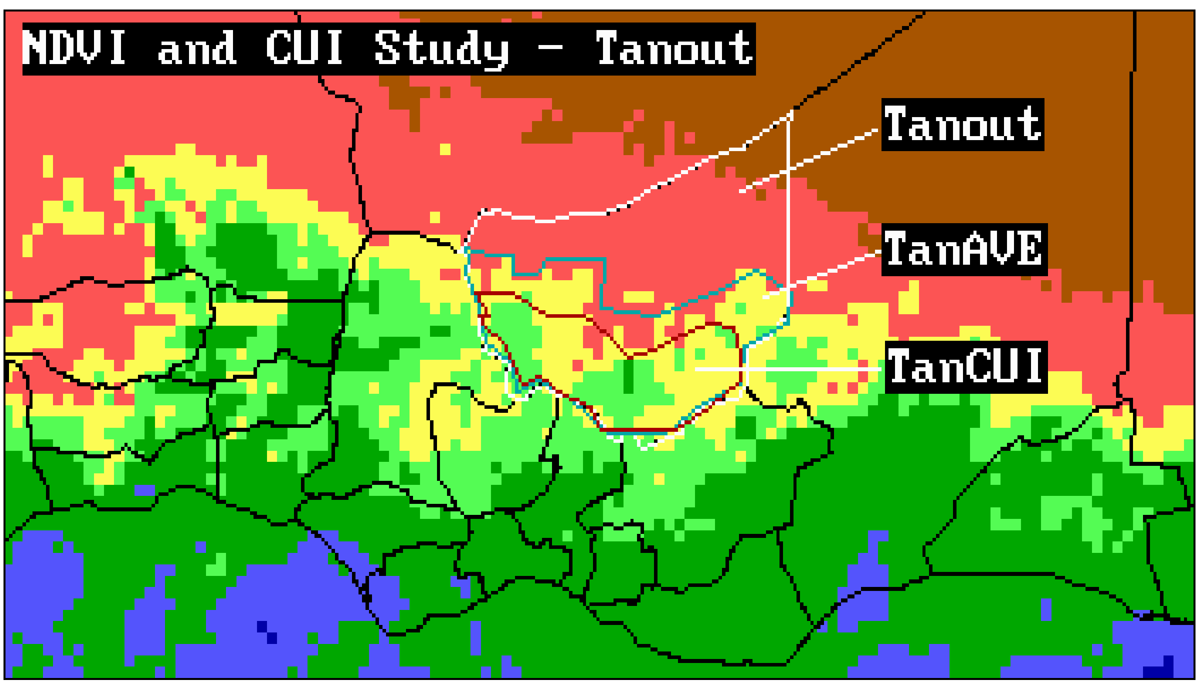


Figure 4. Three different Tanout samples; entire arrondissement (TANOUT), the historical, average maximum NDVI value (TANAVE), using CUI class 1,2,3 only (TANCUI). NDVI image is long term, maximum NDVI value, color coded as red = no vegetation, yellow = low density, green = medium density, blue = dense vegetation.



Several adjustments had to be made in some of the test sites. Segou, which is an intensive agriculture zone, did not have any "non-vegetated" pixels using the NDVI threshold of 0.12 for the long-term maximum NDVI image. In this case, the NDVI threshold value was increased to 0.30 to simulate different levels of vegetation. A similar case was found in Zambia, where the entire study site had very high NDVI values and thus, the vegetation vs. non-vegetation threshold did not apply. In Zambia, two levels of CUI were used to simulate different intensities of vegetation, where MUMCUI1 is CUI class 1,2, and 3 only, and, MUMCUI2 is CUI class 1,2, 3and 4. Finally, the Yatenga unit did not show any agricultural areas in the CUI image for class 1,2, or 3, so the criteria was extended to include CUI class 4 for Yatenga. Table 2 gives the coding for the different scenarios.

Table 2.

Study Site	Admin. Unit Only	CUI-derived within Admin. Unit	NDVI-derived within Admin Unit
Tanout, Niger	TANOUT	TANCUI	TANAVE
Yatenga, Burkina-Faso	YATENGA	YATCUI	YATAVE
Segou, Mali	SEGOU	SEGCUI	SEGAVE
Mumbwa, Zambia	MUMBWA	MUMCUI1	MUMCUI2

Prior to presenting the results of different scenarios, it is useful to describe the test sites relative to agricultural production. Table 3 shows the average millet and sorghum production (average of 1985-1992) for the West Africa test sites, average area planted, average yield (kg/ha), total area of the administrative unit, and percent area planted to millet and sorghum (where production, in metric tons (MT) = area (in ha) X yield (in kg/ha)). These figures are summarized from historical agricultural statistics for the various countries. Tanout and Yatenga produce about the same amount for total cereals (80,000 MT), however, Tanout has twice the area planted and half the yield. Segou produces nearly 6 times as much as the other two sites (460,000 MT), with only twice the area as Tanout, but 3 times the yield. In terms of relative area planted to millet and sorghum, Tanout and Yatenga have only 10 and 13 percent, respectively, while Segou has over 40 percent of the of the overall administrative unit planted in millet and sorghum. The Zambia study site is considered an average production zone that produces mostly corn, cotton, sunflowers and groundnuts and production figures are not necessarily comparable with cereals in the Sahel.

Table 3.

Study Site	Average Cereal Production (MT)	Average Area Planted in Cereals (Ha)	Average Yield (Kg/Ha)	Total Area of Admin. Unit (million Ha)	Percent of Area in Cereals
Tanout	83500	333000	250	3.31	10
Yatenga	79000	160000	490	1.26	13
Segou	460000	630000	730	1.53	41

In terms of yields, Segou is the most productive, followed by Yatenga and then Tanout. The production and yield figures in Table 3 can be used to get a feel for the magnitude of the NDVI values relative to the agricultural production. Keep in mind, however, that the NDVI values represent total biomass (crops, grasses, forest, etc.) and not just agriculture. With the relative production figures in mind results of NDVI curves will now be presented.

5. Results and Discussion.

Figures 5 and 6 shows the NDVI curves for the administrative units only for the three West African sites (first scenario in Table 2). For West Africa, the NDVI statistics were extracted for the rainy season only - from the first dekad in May to the last dekad in October. All three curves show a similar seasonal trend - where the NDVI values are low (below 0.10) during the dry season and begin to rise following the first rains around April or May. The maximum NDVI (or peak of season) is reached sometime in August or September and then the NDVI values begin to decrease as the crops reach maturity and the harvest begins. By the end of October, most of the crops in the Sahel have been harvested and the NDVI values indicate residual agricultural vegetation, as well as forests and grasslands. Notice that the peak of the NDVI curve (or seasonal maximum) is highest for Segou, followed by Yatenga, and then Tanout.

In Southern Africa (Zambia), the NDVI trends are offset to reflect the main agricultural season in the southern hemisphere – with a low in Aug.-Oct. and reaching a peak in Dec.-Jan. (see Figure 6). Notice that the average maximum NDVI value is nearly 0.50, and the minimum, off-season value is still around 0.20 (i.e. higher than the maximum for Tanout). The y-axis in the following graphs was set to the maximum value for the four study sites to facilitate comparison across countries. Some countries, especially in southern and eastern Africa, will have multiple seasons, but this phenomenon is not addressed in this study.

5.1. Comparison of long term average with different years.

The overall, average NDVI values presented in Figures 5 and 6 clearly show the seasonal trends in NDVI. These trends are related to the amount of biomass that is developing on the ground and represent characteristic curves for vegetation development in the given areas. The graphical representation of NDVI is another way of looking at what is depicted in the maps that are used routinely by FFRs to monitor the agricultural season. The color tables in the maps are designed to highlight the changing values in NDVI. When the NDVI values are low (less than .10), they are color-coded red or brown to represent “no vegetation”. As the season progresses, and the NDVI values increase, the colors in the map reflect the rising values - i.e. increasing vegetation. However, the real power in using NDVI to monitor vegetation development, in the FEWS context, is interpreting the maps (or graphs) in terms of how this season relates to the “normal” season.

The next series of graphs (Figs. 7 - 10) illustrate these same trends, extracting the values for different years, and again using the entire administrative unit as the boundary file. Years were selected to show; a drought situation (1984), a poor year (1990), and a good year (1994) in the Sahel. For the Zambia test site, the years chosen were 1991/92, 1993/94, and 1995/96.

The curves are representative of the different years and provide validation for using NDVI to monitor general trends in vegetation development. In 1984, a major drought year in the Sahel, all three West African sites show very little vegetation development. In Tanout and Yatenga (Sahelian zone) there was essentially no vegetation development, whereas in Segou (Sudanian zone), there was some development and then a sharp decrease. The excellent year of 1994 is also very descriptive and shows above average vegetation development in all sites. In 1990, the NDVI patterns are more subtle, but denoting a poor season in the Sahel, when the rains began as expected, then quit suddenly, at mid-season. This can be seen in the NDVI curves around the 1st or 2nd dekad in August in Tanout and Yatenga, when the values begin to drop from normal. Notice also that the Segou region continued on a normal to above-normal trend for that same year.

Several words of caution should be noted when interpreting the differences between the various curves. In some cases, the rainy season may start a few weeks earlier (or later) than normal, and this will be reflected in the position of the NDVI curve relative to normal. This is evident in the Yatenga and Segou curves for 1994, when the season started earlier and more vigorously than usual. Also, beware of “false” dips and peaks which could be related to cloud contamination as is evident in the Zambia curves. There are also “false” dips evident around the 1st of September in the Segou (1984, 1994) and Yatenga (1994) curves. It is highly unlikely that vegetation would respond so dramatically, so quickly.

Another source of variation is introduced when the satellites change, and although there was some effort to calibrate the different satellites that were used to construct the historical NDVI database, there are still some differences between years. For example, in the dry season in the Sahel, there is essentially no vegetation and the values in May should be the same between years. There is a slight variation, on the order of .03-.05 between years. The wild fluctuations in Zambia in the off-season are due to clouds (a difference of over .10), and this is a common problem for NDVI interpretation in southern and eastern Africa. To be on the safe side, a threshold value of .03 or .04 is typically used to depict a “real” deviation in difference images.

5. 2. Comparison of different sampling scenarios for different years.

The next set of graphs (Figs. 11 - 26) illustrate the different sampling scenarios (described in Table 2) for the same years of data for each of the study sites. Keep in mind the above discussion describing the potential sources of variation in the NDVI statistics. The Tanout series (Figures 11 - 14) shows the same basic trends in the NDVI curve for all sampling scenarios. Except for 1984, the overall administrative unit (TANOUT) is slightly lower than the other two scenarios (TANAVE and TANCUI) during the growing season, on the order of .02-.03. In 1984, the curve is essentially flat for the entire season. During the dry season, there no difference between the three samples. The relationships between the curves is the same for the Yatenga examples (Figs. 15 - 18).

The results for Niger are consistent with a previous study by USGS (see Klaver report, 1995). In that study, a similar approach was employed to investigate the utility of stratifying NDVI imagery by different levels of CUI. In addition to varying the stratification technique, Klaver also looked at different rasterization techniques - the process of converting the digitized CUI lines to image format. Klaver found variations between the different stratification techniques, and the different rasterization procedures, but these variations were of the same magnitude as reported in the current study (i.e. .02 - .04 NDVI values).

The Segou curves (Figs. 19 - 22) are similar to Tanout and Yatenga, with one variation - the CUI curve (SEGCUI) is slightly lower than the other two samples (SEGOU and SEGAVE) in all cases. The biggest difference is in the 1994 example (the good year) in the month of July, where the CUI values are .07 below the average curve. Recall, the large dip at the 1st of August is due to clouds. Further inspection of the NDVI images reveals a “red” spot (poor vegetation development) in southern Segou for this time period. The CUI sample is taken mostly from southern Segou and this case illustrates how a vegetation anomaly could be enhanced if the sample area was more precisely identified. The northern section of Segou could also be more forested, which would give a slightly higher value than the croplands in the south.

In the Zambia cases (Figs. 23 - 26), the patterns seem inverted, with the agricultural season having less variability than the off-season. The MUMCUI1 case is slightly lower than the other two cases, with a maximum difference of .07 in April of the 1993/94 season. This pattern seems similar to the Segou curves, where the more intensive agricultural zones have a slightly lower curve when compared to the adjacent areas. Again, this may be due to forested areas dominating the NDVI values, so the stratification may be picking up some differences in vegetation types. However, the differences are relatively small in most cases, in terms of general trends or relative magnitude, and especially in light of how these data would be used by the FFRs. A significant anomaly in the NDVI trends should still show up -- in image form or, in the curves – and this is the most common application for FFRs.

Also, except for the Segou case in 1994, there is very little difference between the AVE and CUI samples in most cases - implying that the vegetation/non-vegetation line derived from the long term NDVI database has about the same effect as stratifying by CUI classes. Especially when one considers the resolution of the satellite imagery (NOAA, GAC resolution at 7 km) in comparison to the detail available from the original CUI maps (from Landsat, at 80 m resolution). The GAC pixels are so general to begin with, and along with all the variations in NDVI values, the CUI seems too detailed for use with GAC data. The detail is lost on the large GAC pixels compared to the modest sensitivity of the NDVI values which are commonly observed.

5.3. Comparison of different administrative levels in Goure

The differences between the various sampling scenarios given above were subtle in most cases, therefore an extreme case was explored to illustrate the utility of stratifying the NDVI images. The arrondissement of Goure (administrative level 3), in eastern Niger was selected as an example of a very large administrative unit that crosses several agro-ecological zones (see Figure 4). In fact, the land area of Goure is greater than the combined area of Rwanda and Burundi.

Figures 27 and 28 show the results of stratifying the Goure arrondissement by several different scenarios. The case illustrated in Figure 27 was selected in the same fashion as the study sites previously presented, e.g. GOURE, GOURCUI, and GOURAVE. The difference is noticeable, especially since over 75 percent of the Goure arrondissement is desert, which is reflected in the graph by a fairly flat curve for the entire administrative unit. When the vegetated areas in the southernmost parts of the arrondissement are isolated, there is a very distinct NDVI curve.

Figure 28 illustrates one last example of sub-sampling to extract NDVI statistics. In this case, the admin-4 level boundary files were used to compare with the three scenarios above. GOURE is administrative level 3, NI4GOURE is level 4 (canton), ZR-GOURE is the remainder of the arrondissement (i.e. the desert regions). It is obvious from these graphs that some type of stratification is needed in the case where large administrative units cover very diverse agro-ecological zones.

6. Conclusions and Recommendations.

Based on the previous discussion and presentation of the results of the NDVI study, the following conclusions and recommendations are presented for the use of CUI in the FEWS project.

1. The need to verify the original CUI maps.

The CUI maps were developed as a means to identify important agricultural lands - especially in the absence of adequate land use or land cover data. Although the CUI classification system has been validated in the U.S. context, there has not been an extensive, formal verification of the CUI maps that have been created for sub-Saharan Africa. Several small-scale projects have reported optimistic, but inconclusive, preliminary results (e.g. Bruner et al., 1995; Dalsted and Westin, 1996; Crawford et al 1996). To enhance the utility of the CUI maps a more rigorous evaluation would need to be made before they can be used in a quantitative sense to stratify NDVI data or redistribute agricultural statistics. However, the cost (mostly time and energy) of a more rigorous evaluation is beyond the scope of most FFRs, especially considering the marginal gains in improving the analysis capabilities as presented below.

2. The use of CUI to enhance the extraction of NDVI statistics.

NDVI data are used routinely by most FFRs as a vegetation monitoring tool, usually in form of a color coded “greenness” or “difference” map. Occasionally during the agricultural season and once a year for VAs, the FFRs compute NDVI statistics based on existing administrative unit boundaries (although this is not done in all countries). The results of this study suggest that, given the basic applications of NDVI used by most FFRs, there is very little to be gained, in most cases, in stratifying by CUI classes. Most FFRs focus their analysis on the map form and any major anomalies would be easily detected and interpreted in the images. If more quantitative analysis is needed in the form of NDVI curves in SPACEMAN, the major anomalies would also most likely be detected in either case - with or without CUI stratification. Considering the complicating factors such as the coarse spatial resolution of the GAC imagery and the effects of clouds and haze (especially in Eastern and Southern Africa), there is little to be gained by stratifying GAC imagery by CUI classes.

There may be certain situations where some type of stratification is needed prior to extracting descriptive NDVI statistics (e.g. Goure, Niger). In large administrative units, such as Goure, with diverse agro-ecological zones, more appropriate boundary files should be created for extracting NDVI statistics. A country-by-country review should be conducted to determine where these extreme cases exist. In these cases, a special NDVI boundary file could be created to isolate the areas of interest, excluding large desert regions, or areas otherwise known to be non-agricultural (e.g. forests, rangelands, wetlands, etc.).

In most cases, boundary files can be created manually by FFRs, similar to how the study sites were selected in this review. A few simple tests could be conducted in the various countries to see if there are large administrative units that would benefit from being sub-divided. In most countries, the 3rd level administrative units should be sufficient to extract a relatively homogenous sample of NDVI pixels. If further sub-division is deemed necessary, the FFR can attempt to create new boundary files themselves, or request assistance from FEWS/W. Alternatively, FEWS/W could work with USGS to determine which countries would benefit by sub-dividing administrative units, and create the appropriate sampling units. These can obtained from existing CUI maps, the long-term average NDVI images, or some other source of land use classification.

These boundary files should be incorporated into the SPACEMAN software so that a historical, NDVI, database could be created relative to the modified polygons. The SPACEMAN program could also be enhanced to extract basic NDVI indicators that might be considered for use in the VA process. This has been a time-consuming process in the past, but these procedures could be easily programmed into a FEWS Data Manager routine. This would save valuable time for the FFRs each year during the already busy VA process.

3. The role of CUI in redistributing national agricultural statistics.

The national agricultural statistics in most of the FEWS countries usually do not provide the level of detail required to assess the agricultural production status at the sub-national level. The CUI maps were proposed as a means to disaggregate the agricultural statistics so that the analyst could focus only on those areas that are most important in terms of agricultural production. However, there is some question as to the reliability of going through this process. From a statistical sampling perspective, the national agricultural statistics are designed to provide reliable production estimates at a certain level and are not necessarily valid below that level.

If the CUI maps were to be used to redistribute agricultural statistics, we would need to have some type of confidence limit placed on the mapping to help FFRs interpret the results. This confidence limit would also be necessary in a practical sense, to explain how far we can “push” the analysis and results, and for FFRs to explain to other users and decision-makers the implications of redistributing national agricultural statistics, i.e. to present the results of redistributed statistics to an international donors meeting audience. As mentioned above, this level of verification has not been done for CUI maps in sub-Saharan Africa and is beyond the scope of the current FEWS project.

There are some cases where this type of exercise is needed to fill in missing data, or account for changes in national administrative boundaries. If there is a need to use this type of approach, this could be made available to FFRs, on a country-by-country basis, such as the Ethiopia example. Most FFRs use the agricultural statistics as they are given, as an estimate of sub-national production, and supplement their analysis with more detailed information from other sources or from field trips to complete localized food needs assessment and targeting of specific populations of vulnerable people. If the disaggregated statistics are “better than nothing”, then the use of this procedure may be appropriate. This would be determined on a country-by-country basis.

4. Utilizing other sources of data.

Contrary to the early days of FEWS, there are more sources of land-use and crop-use maps available for many countries, and these should be investigated as an existing and cost-effective means to acquire the necessary crop-land masks. Currently, USGS and FEWS are investigating the use of a FAO soil moisture requirements model and a new land classification system, derived from the 1 km (LAC) NDVI image mosaic. The FAO has recently published a very detailed report for the "Crop Production System Zones of the Intergovernmental Authority on Drought and Development sub-region" (FAO-IGADD, 1995).

Maps such as the ones presented in the IGADD report should be investigated as an alternative estimate of crop use, at least for eastern Africa. Similar reports and databases have been appearing in other countries as well (e.g. Norwegian land-cover database from Uganda). Utilizing existing databases, if the content is adequate and appropriate, will not only provide FEWS with important information, but foster collaboration with the early warning community as well (e.g. IGADD and AGRHYMET). This has already begun in several countries (e.g. Burkina-Faso and Mali). The AGRHYMET Regional Center is also distributing CUI maps as a baseline for monitoring and evaluation programs for natural resource projects, and this could be an opportunity for collaboration and support to a regional early warning system. The existing CUI maps should be shared with other groups and national ministries so they can profit from the extensive mapping effort that has been done.

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